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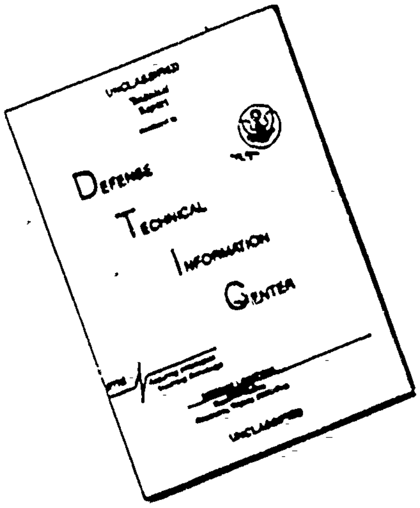

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A Suggested Method of Increasing the Damping of Aircraft Structures

by

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R.&D.

SUMMARY

The object of this work is to find means of increasing damping in the joints of s structure, similar to a riveted structure by the use of plastic inserts in the joints.

Information on the effect of pressure cabin sealing and the adoption of spot-welded or Redux* welding construction is also given.

This report discusses the operation of an insert, the properties called for in service and recommends four suitable materials for further tests.

The apparatus used to compare the damping of inserts made from a number of different materials is described. The effect of thickness of insert on damping has been investigated and the variation of damping with temperature has been obtained between -25° and +25°C. for the material Poly-iso-butelene.

Conclusions

These investigations show how, by means of an insert of Poly-iso-butelene, it is possible to increase the damping of a riveted structure. For vibration at a frequency of 36 cycles per second the damping is increased 200% for a maximum dynamic stress in the test specimen of 70 lb./sq.in.

For stresses higher than this but within the elastic range of the structure a larger increase in damping may reasonably be expected.

* A means of joining metal plates by the insertion of thermo-plastic, which is fused by the application of heat and pressure.

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Further Developments

Specimens with Poly-iso-butelene should be given extensive fatigue tests and if satisfactory a trial of this form of construction should be made in the construction of a separate tail plane unit or similar part of an aircraft.

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1 Introduction

The work on damping described here has been undertaken as a result of the conclusions reached by previous investigators(1) and suggestions made by S/Ldr. W.Fiszdon for the introduction of artificial damping into aircraft structures.

Previously, however, it had been stated by Walker(2) that the damping capacity of an aircraft structure was twenty or more times that of the constituent material, due to friction at joints and other effects.

As little is known of the behaviour during rubbing at the joints of components used in aircraft structures comparative measurements of damping have been carried out on laminated beams.

2 Discussion of Joints in Aircraft Structures

For a beam formed of two horizontal strips and subjected to forced vibration so that it bends in the vertical plane, the amount of slip at the interfaces decreases with increasing pressure, but the energy dissipated by friction reaches a maximum value at some intermediate pressure between the two limiting conditions of no slip and zero pressure. This is dealt with more fully in the appendix, where it is demonstrated that small variations in rivet-pressure that would be expected between specimens at the lap joints of an aircraft produce negligible changes in damping, and for this reason no great error is likely to have been introduced by drawing conclusions from single test specimens of the various types.

2.1 Choice of Insert

It has been found possible to increase the damping of laminated beams by the use of inserts of materials with high internal damping, such as fabrics, rubbers, cements, sealing compounds and adhesives. Values of the damping capacity for various materials are given in Tables I, II and III and some of these materials have been selected for further tests in tubular specimens (Fig.10) taken to represent a monocoque aircraft structure.

Examination of a number of aircraft riveted joints of which typical cross-sections are shown in Figs. 11 and 12, reveals the existence of gaps which in a metal-to-metal lap joint (Fig.11) vary from 0.0 to 0.006 in or in a joint sealed with compound (Fig.12), from 0.007 to 0.03 in. The inserts recommended are sheets less than 0.006 in. thick of Poly-iso-butelene, Poly-vinyl-chloride, Polythene or Nylon fabric or a solution of Poly-vinyl-acetate.

The choice of a material for inserting in the skin joints of a wing and fuselage is governed by the following properties:

Resistance to fatigue.

Lack of hygroscopy.

Minimum inflammability.

Resistance to corrosion.

Freedom from attack from organic matter.

Retention of properties with age.

Consistency of properties at temperatures between 100°C. and -40°C.

Lack of creep.

The materials Poly-iso-butelene, Poly-vinyl-chloride, Polythene, Nylon fabric or a solution of Poly-vinyl-acetate are considered to have suitable properties though the problem of fatigue has not been fully investigated (see para. 4.3).

2.2 Electrical Insulation

As the high insulating property of these plastics provides no leakage for an electric charge which may be induced care should be taken to see that all parts are earthed.

2.3 Welded Construction

The damping capacity of a tubular specimen of spot-welded construction, similar in other respects to that shown in Fig. 10 was measured and found to be approximately 80% greater than that of riveted construction.

The use of Redux welding (i.e. insertion of thermo-plastic between the plates at the joint and fusion by means of heat and pressure) in place of bolts in laminated beam 1 (para.4) has reduced the damping capacity by 75%.

2.4 Pressure Sealing Compound

The influence of pressure sealing compound applied to the exterior of beam I was to increase the damping 250%.

3 Tubular Test Specimens

3.1 Description of Test on Tubular Specimens

Tubular specimens, approximately 5.5 ins. diam. and 5 ft. long, were made of 22 s.w.g. dural sheets with seams riveted or spot welded with two runs $\frac{1}{2}$ in. apart, $\frac{3}{4}$ in. pitch along circumferential seams and $\frac{1}{2}$ in. pitch along longitudinal seams (Fig.10).

The tube was simply supported across a horizontal diameter at each end on ball bearings to give minimum friction at the supports.

The specimen was vibrated in its fundamental mode by attaching a linear vibrator as shown in photograph: the out of balance being adjustable in steps. The resonance frequency was controlled by adding lead weights at the centre of the tube.

The maximum static stress in deflected position in the specimens was about 80 lb./sq.in. and the internal damping in the material was negligible.

3.2 Measurement of Damping Capacity

The amplitudes at the centre of the specimen were measured with an R.A.E. eddy current pick-up[3] with associated circuits deflecting the beam of a cathode ray tube, and the resonance curve of amplitude against frequency was plotted, as shown in Fig. 1. The damping capacity was obtained by graphical means and denoted as a dimensionless coefficient

$$\text{Damping capacity} \left(= \frac{\text{Damping coefficient}}{\text{Critical value of coefficient}} = \right) \; C/C_c \; (g) = \frac{\Delta N}{2N},$$

where ΔN (AB in Fig.1) is the frequency spread at an amplitude $1/\sqrt{2}$ of that at resonance and N is the frequency at resonance.

Values were also obtained from amplitudes measured at resonance and were denoted

$$\text{Damping capacity} \quad C/C_c \; (A) = \frac{1}{2\,m\,W_n^2} \cdot \frac{P_o}{x_o}$$

where m is the equivalent mass at the centre.

P_c the applied harmonic force.

x_o the maximum amplitude at the point of application of the force.

W_n the frequency at maximum amplitude.

3.3 Note on Units

Damping capacity = relative damping $\times 2\pi$

= logarithmic decrement $\div 2\pi$.

3.4 Results

A curve representing the damping of a riveted tubular specimen at frequencies between 24 c.p.s. and 40 c.p.s. is shown in Fig.2. At the low frequencies it was possible to take readings at amplitudes between 0.0025 and 0.006 in; the damping was independent of amplitude. A similar curve for a tubular specimen with a 0.006 in. thick coat of poly-iso-butelene painted on the joints before assembling, shows that, by this means, the damping can be increased between 100 and 190% when the amplitude is 0.0025 ins. and a greater amount when the amplitude is 0.006 in. With an insert of 0.006 in. thick poly-vinyl-chloride the damping was raised uniformly 70%.

For a given excitation, the amplitude at resonance will be inversely proportional to the damping.

The damping of a Bostik insert is also given in Fig. 2, but above 30 c.p.s. the results were inconsistent and it is thought that they could not be repeated with certainty on account of fatigue and recovery effects.

4 Tests on Laminated Beam 1

To find the most effective damping material, different inserts have been tested in a laminated beam made of two steel strips 40 in. $\times$ 3 in. $\times$ 15 s.w.g. held together by equally spaced 6 B.A. bolts tightened to a known torque.

This beam was suspended flexibly at the nodes and excited in the fundamental mode by a linear vertical vibrator placed at one end.

Resonance curves were obtained from the amplitudes at the vibrator which were scratched directly on to waxed paper.

The results of these tests are given in Table I and indicated that Bostik C and Poly-iso-butelene were suitable for further testing.

4.1 Laminated Beam 1 with P.I.B. Insert

By using a solid beam it has been estimated that the internal damping of the metal and the external damping of the air, supports and attachments makes $C/C_c = 0.0015$; taking this into account it will be seen that the P.I.B. insert increases the damping beyond that of the metal-to-metal beams about 200% for an insert 0.003 in. thick and about 400% when it is 0.008 in. thick.

Since there is a small variation in damping with amplitude other measurements on this beam were taken at approximately the same maximum amplitude.

4.2 Variation of Damping of P.I.B. Insert with Temperature

The variation in damping with temperature has been measured between -25°C. and 25°C., the work at lower temperatures being done in a cold chamber.

At lower temperatures the stiffness of P.I.B. increases which is shown by the rise in resonance frequency: and in this region the damping capacity is reduced. The remaining properties of the material are not affected by reduction to -40°C. and on return to normal temperatures recovery is complete.

4.3 Fatigue Test

There was no change in the damping properties of Poly-iso-butelene after continuous vibration in Beam 1 for 3 hours which gave 264,000 reversals.

5 Tests in Laminated Beam 2

Beam 1 was replaced by beam 2, which consisted of two dural sheets, one 26 in. × 3 in. × 22 s.w.g., the other 26 in. × 3 in. × 10 s.w.g. bolted together with 23 6 B.A. bolts to obtain similar pressure on the inserts as that obtained with riveted joints. Table II gives the results of testing a number of materials in this beam while it was vibrated in its second natural mode, (i.e. with three nodes) suspended flexibly at its outer nodes. In Fig.5 is plotted the damping capacity of a number of materials of various thicknesses which shows a general tendency to increase with thickness for thicknesses above 0.010 ins.

Assuming an equivalent cross-section and obtaining the radius of curvature for the central sections of the beam from the amplitudes measured at several points, the maximum travel at the faces of an insert 0.006 in. thick has been estimated at 0.005 ins. Whether this causes slip, shear strain or both is not known, but where the thickness of insert approach the same order of magnitude as the relative movement between plates, the damping increases sharply particularly for the thermo-plastics. The comparatively high damping of the two adhesives, Cellobond 1055 and Poly-iso-butelene is thought to be due to penetration around the bolts. The damping properties of thermo-plastics are dependent on the use of different plasticisers and it is necessary to take this into account when comparing their properties.

6 Stiffness and Strength of Joints with Inserts

Employing the specimens shown in Fig.7, static tensile tests were made on riveted specimens with and without inserts to determine the stiffness and strength. Some typical results of these tests, are given in Fig.8, the difference in stiffness with and without inserts is negligible.

Attempts to measure the hysteresis loss with this specimen were inconsistent and are not quoted: but inconsistency may be due to its being dependent on the rate of loading which was not closely controlled.

7 Pressure-cabin Sealing Compounds

The increase in damping capacity due to external application of a pressure cabin sealing compound "Solufix 10" is shown at the bottom of table I to be 186%.

8 Redux Welding

A beam of type 1, in which the layers were not bolted but welded with Redux was found to have a damping capacity 0.002 which is $\frac{1}{4}$ that of the same beam bolted together. The damping capacity of beam II was similar to beam I with no insert.

9 Conclusion

These investigations show that by means of an insert of Poly-iso-butelene between 0.006 and 0.008 in. thick, it is possible to increase the damping of a riveted structure. For vibration at a frequency of 36 c.p.s. the damping increased by 200% for a maximum dynamic stress in the test specimen of 70 lb. per sq.in. For stresses higher than this value but within the elastic stress range of the structure a larger increase in damping may reasonably be expected.

10 Recommendations for Future Work

The damping of aircraft quoted in Table III is greater than that of the tubes because the specimen did not represent the secondary structure and equipment of an aircraft.

It is recommended therefore that further tests be carried out on a representative part of an aircraft structure (e.g. tail plane assembly) incorporating the appropriate insert at the joints.

Improvements would be obtained in the tubular test specimens by constraining outer ring of the ball race in vertical direction and by making the diameters at the two ends of the specimen equal through a more symmetrical arrangement of the diameters of the component sections. The present arrangement introduces a slight axial pitching movement of the lead weights introducing coupling in the modes of vibration and slight errors in estimation of input energies at certain frequencies.

Any discrepancy between tubes and beams, is probably due to the use of bolts in place of rivets and it is suggested that in future, materials should be tested provisionally in riveted beams.

It may also be concluded from Table III that where rivets are used, adhesives are more effective in damping than sheets, partly on account of their ability to penetrate further.

References

Ref.No.	Author	Title, etc.
1	Fiszdon, W., Jones, R.P.N. and Woodcock, D.L.	Effect of damping in different parts of an aircraft structure on forced vibrations as studied on simplified systems. R.A.E. Report S.M.E.3317, April, 1945. A.R.C.8759, 0.496.
2	Walker, P.B.	Note on material and structural damping. R.A.E. Report No. AD.3079, November, 1936. A.R.C.2717, 0.55.
3	Nahmani, G.	An eddy current pick-up for measuring linear vibrations of metal parts. R.A.E. Report No. Eng.4105. March, 1944.
4	Walker, P.B.	Theory of sinusoidal oscillations with variable damping and excitation. R.A.E. Report No. AD.3073. June, 1936. A.R.C.2516, 0.41.

Attached:

Appendices I and II
Tables I to IV
Figs. 1 to 9 - Drg.Nos. Vib.5014 to 5019
Fig.10 - Neg.No. 60427
" 11 - " " MAT/M.4741
" 12 - " " MAT/M.4741A

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Appendix I

The Effect of Interface Pressure on Damping

Before proceeding with the above tests on damping in laminated beams, it was necessary to obtain some indication of the variation in damping with change of interface pressure at the points of contact of two surfaces.

The technique employed was that of measuring the applied force and amplitude at resonance of a beam made of two strips, (described in para.4) bolted together to known torque loadings with the aid of a spring-loaded spanner.

The curves obtained are shown in Fig.9 for a chamois insert and for a metal-to-metal beam. Both curves indicate that when the torque exceeds 1.0 in.lb. the damping is nearly constant.

No attempt has been made to make use of the friction damping near the peak of the curve, as it would be complicated by its dependence upon factors which are difficult to control such as surface finish and humidity.

The change of resonance frequency which is the result of changes in stiffness and damping is also shown graphically.

Appendix II

Damping of Spot-welded Tube

In order to compare the damping of spot-welded with riveted construction, a tubular specimen was built similar to that described in paragraph 2, but with spot-welds replacing the rivets and tested under identical conditions.

From Fig.2, it will be seen that the damping of the specimen tested was 80% greater than the riveted specimen.

It has been suggested that, where spot welding is used, internal friction may originate at the boundary of the nugget where brittle cast metal is in contact with rolled sheet.

Table I

Laminated Beam I

Insert	Thickness in.×10⁻³	Frequency c.p.s.	Damping coefficient / Critical value of coefficient (Graphical)
None	-	13.5	0.008
Cemtex	-	19.0	0.014
Grease	8	16.3	0.014
Leather	94	26.7	0.015
Canvass	47	22.2	0.021
Plywood	60	25.0	0.022
Insulation tape	22	17.1	0.029
Plasticene	42	20.1	0.032
Durolac	-	13.9	0.035
Bostik	31	17.7	0.037 - 0.043
Dural	15	17.0	0.059
Felt	78	19.6	0.078
Poly-iso-butelene	8	15.1	0.060
Redux weld in place of bolts			0.002
Pressure sealing compound. Solufix 10. (Applied externally)			0.028

Table II

Laminated Beam 2

Insert	Weight of insert lbs.	Thickness of insert in.× 10^{-3}	Frequency c.p.s.	Amplitude at vibrator ±0.001 ins.	Damping coefficient: Critical value (Amplitude)	Damping coefficient: of coefficient (Graphical)
None	-	-	36.0	288	0.0078	0.0072
Paper		14	34.0	202	0.011	-
Dural	0.231	30	43.0	176	0.0128	-
Paper		2.5	37	155	0.0145	-
Bakelised fabric (Phenol formaldehyde)	0.13	34	42.4	133	0.0169	-
Bakelised paper " "	0.13	35	42.7	115	0.0195	-
Felt	-	25.50	-	115	0.0195	-
Leather	0.194	80	51	97	0.0232	-
Perspex	0.203	63	49	90	0.0250	-
Chamois	0.028	18	40	83	0.0271	0.022
Wood	0.112	48	-	55	0.0408	-
Thin Thermo-plastics						
Poly-vinyl-chloride (b)	0.0025	3.5	36.5	111	0.020	0.017
Poly-vinyl-chloride (c)	0.0021	2.2	36.4	94	0.024	0.022
Poly-vinyl-chloride (a)	0.0021	6.0	35.0	68	0.033	0.030
Poly-vinyl-chloride (2 layers)	0.0042	12.0	32.0	104	0.022	0.017
" " " ($1\frac{1}{2}$" diam. washers)	0.0014	6.0	37.0	76	0.030	0.026
Polythene	0.0023	5.0	35.4	69	0.032	0.025
Lassovic tape (Poly-vinyl-acetate)		7.0	35.5	86	0.026	0.021
Cellobond 1055 (PVA based adhesive)		8.0	36.0	65	0.035	0.039
Nylon (woven)	0.0051	4.0	37.0	105	0.021	0.017
Poly-iso-butelene (adhesive)		3.0	36.0	58	0.039	-
Laminated beam 2 (rivets in place of bolts)						
None	-	-	35.0	266	0.0084	0.010
Poly-vinyl-chloride ($1\frac{1}{2}$" diam. washers)	0.0014	6.0	37.0	180	0.0124	0.016

Table III

Comparative Values of Damping Capacity

Item		Frequency c.p.s.	Damping coefficient / Critical value of coefficient	
			Bolted	Riveted
Beam 2	- No insert	36	0.0078	0.008
	P.I.B. insert	33.3	0.028	
	P.V.C. insert	37	0.03	0.012
Tube	- No insert	36		0.0032
	P.I.B. insert	36		0.0094
	P.V.C. insert	36		0.0053
Aircraft	- Metal	36	0.018 - 0.03	
	Bonded wood construction	36	about 0.035	

Table IV

Laminated Beam 2

Effect of Interface Pressure on Damping

Insert	Weight lbs.	Thick-ness in. $\times 10^{-3}$	Torque in Spanner in.-lbs.	Freq.	Amp. at Vibrator	Damping coefficient / Critical value of coefficient
Chamois	0.028	18	0.54		43	0.052
			0.82		79	0.029
			1.04		79	0.029
			1.22		83	0.027
None	-	-	0.26	29.3	100	0.0226
			0.54	30.2	83	0.0272
			0.82	32.0	210	0.0107
			1.04	36.0	227	0.010

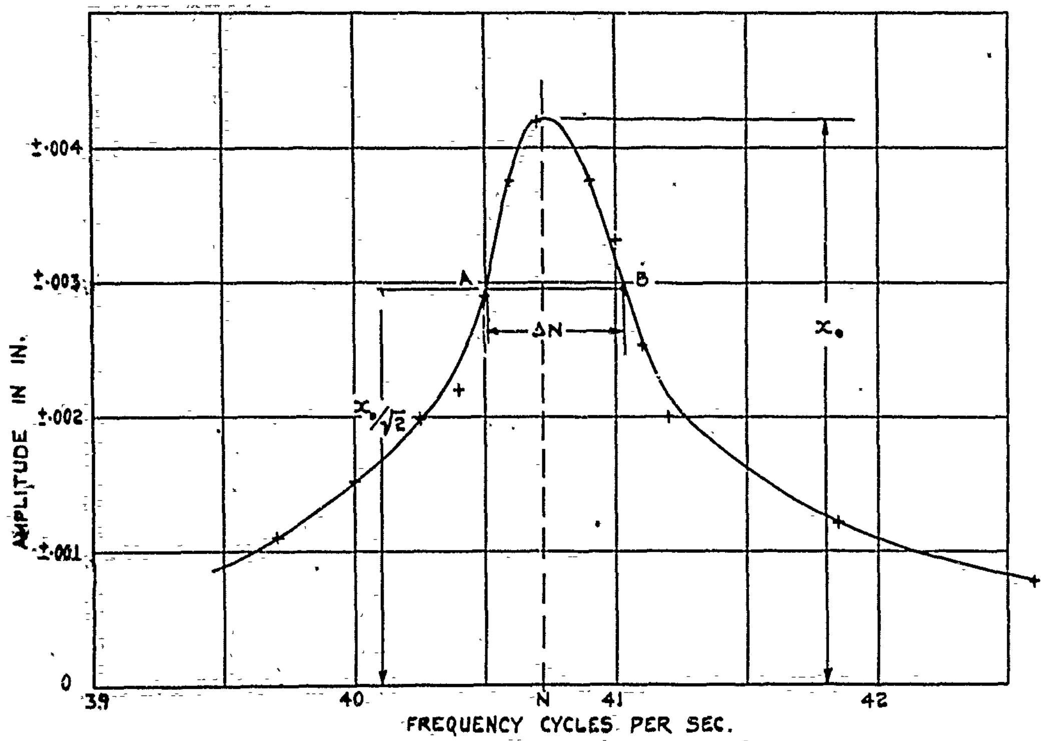


FIG. 1. TYPICAL RESONANCE CURVE OF CYLINDRICAL SPECIMEN.

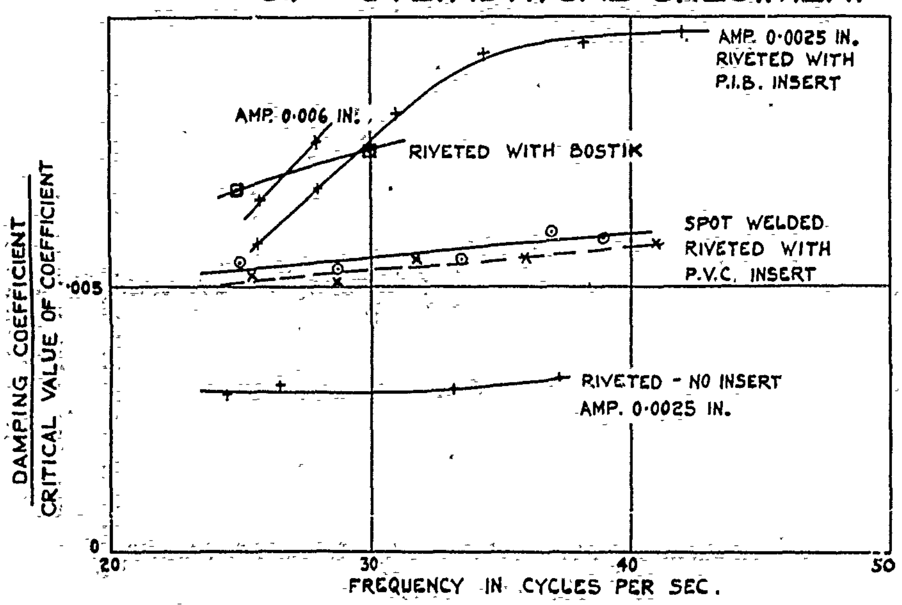


FIG. 2. DAMPING CAPACITY OF TUBULAR SPECIMENS.

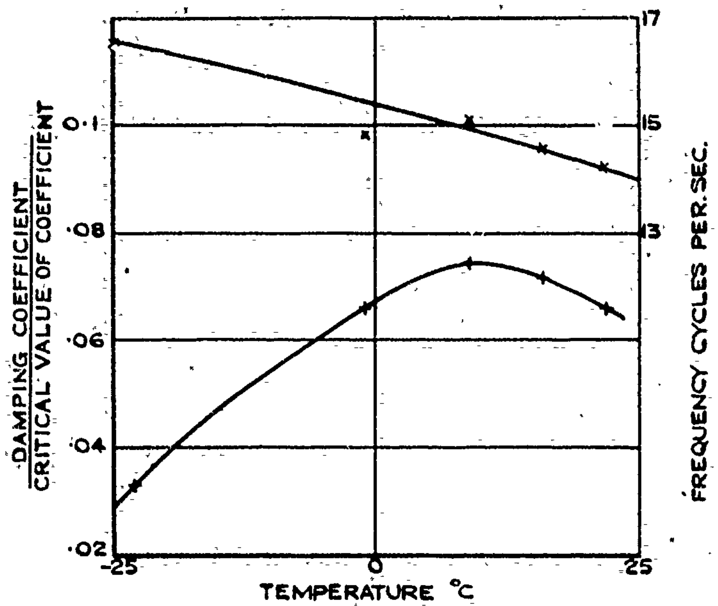


FIG. 3. EFFECT OF TEMPERATURE ON DAMPING CAPACITY & NATURAL FREQUENCY OF LAMINATED BEAM WITH P.I.B. INSERT.

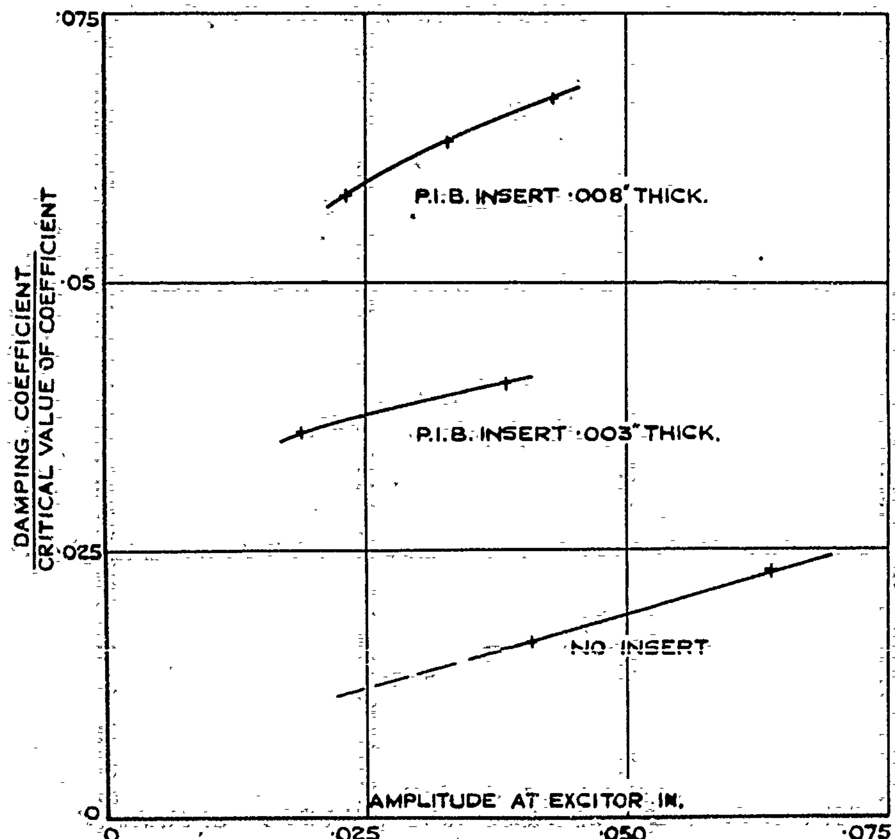
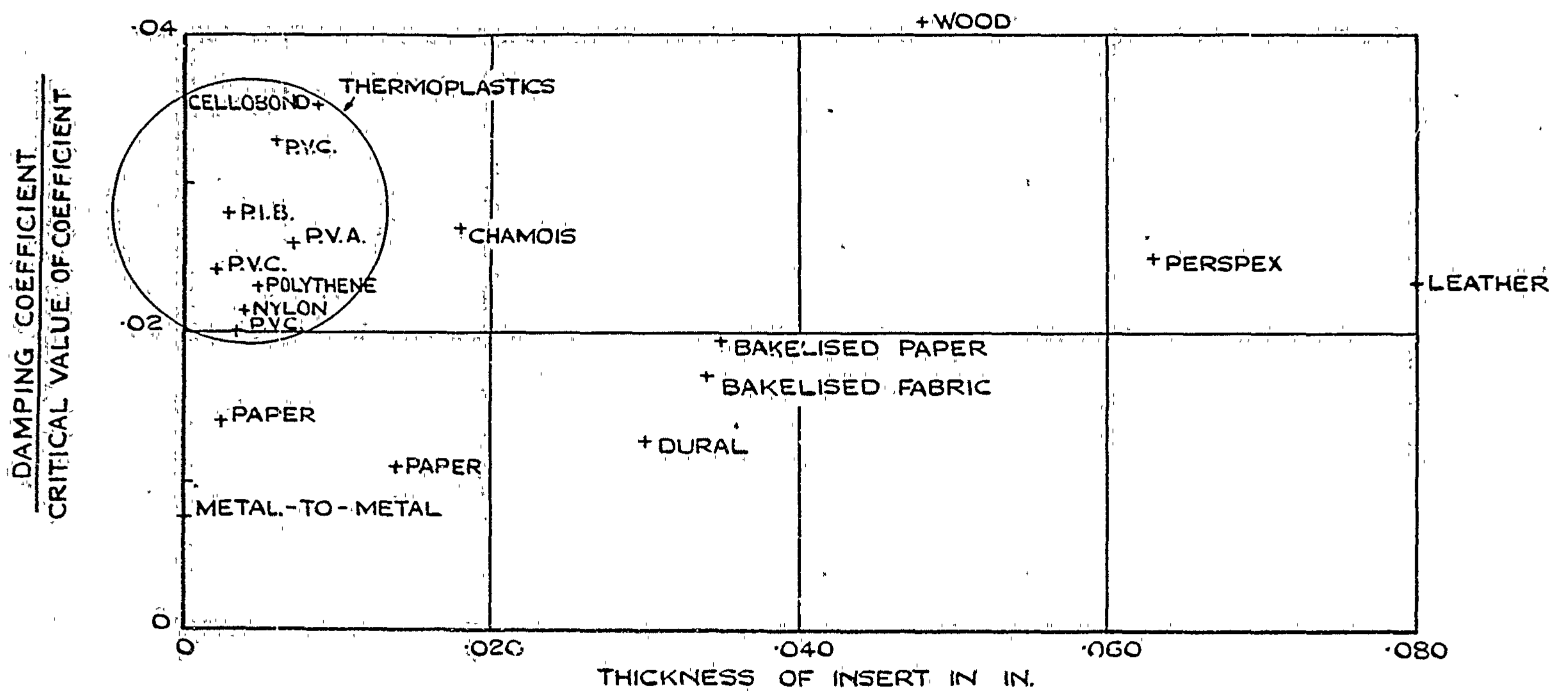


FIG. 4. EFFECT OF AMPLITUDE OF VIBRATION & THICKNESS OF P.I.B. INSERT ON DAMPING CAPACITY OF LAMINATED BEAM I.

VIB. 5016.

FIG. 5.



DAMPING CAPACITY OF A NUMBER OF INSERTS OF VARYING THICKNESS.

No VIBN 5017

FIGS. 6 & 7.

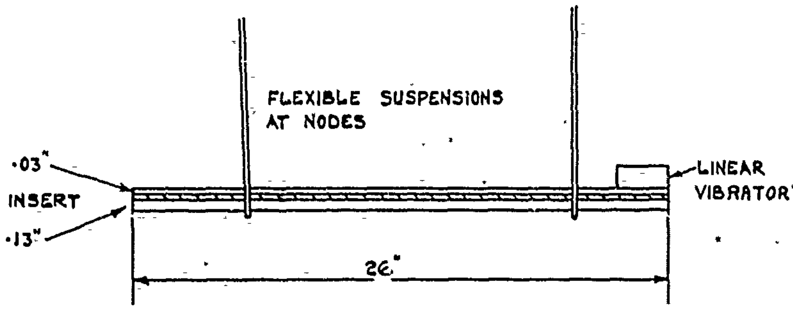


FIG. 6. SECTION THROUGH LAMINATED BEAM II.

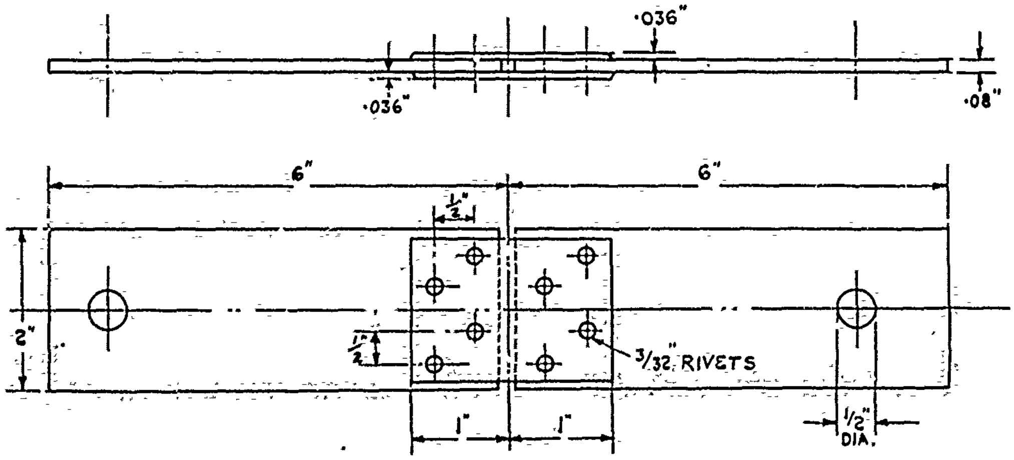


FIG. 7. DETAIL OF SPECIMENS FOR TESTING STIFFNESS ETC. OF BUTT JOINTS.

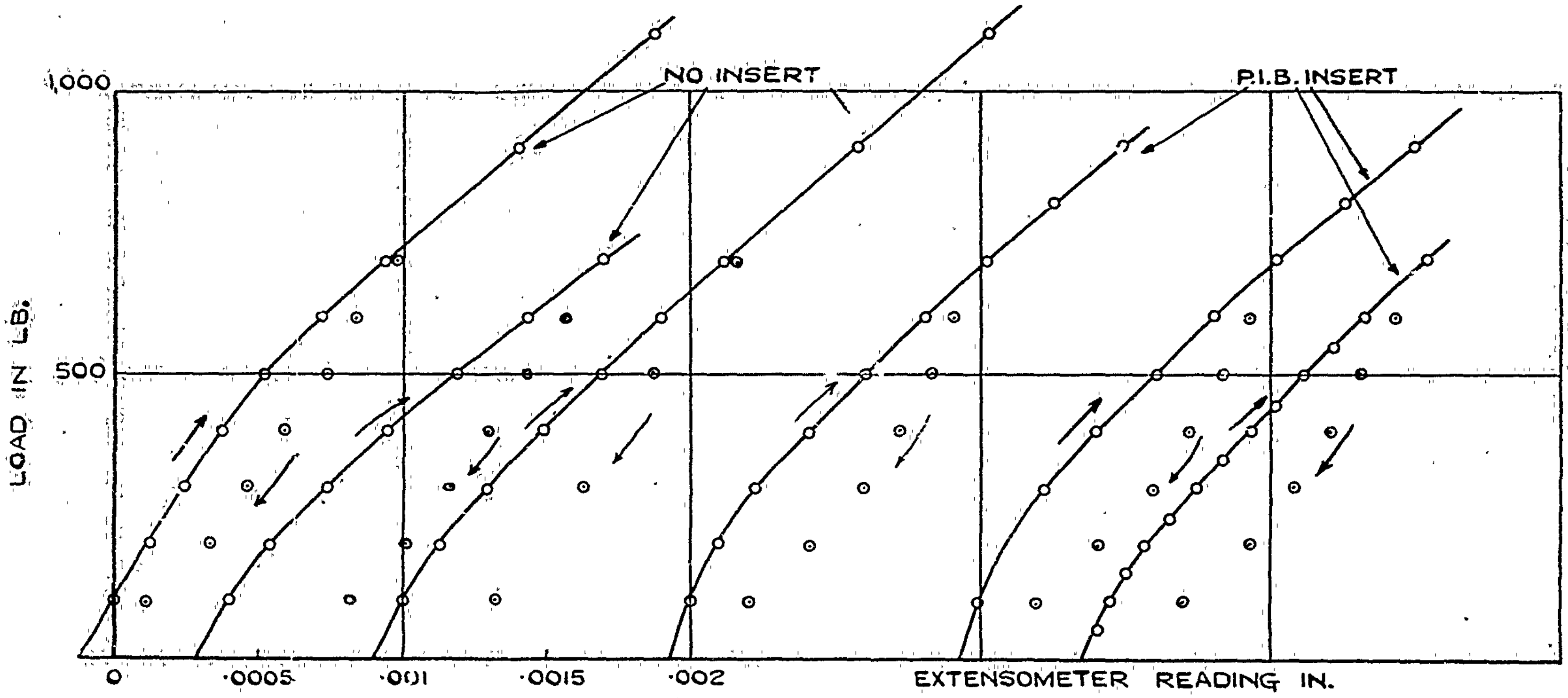


FIG. 8.

TYPICAL LOAD EXTENSION DIAGRAMS FOR TEST SPECIMENS WITH & WITHOUT INSERT OF P.I.B.

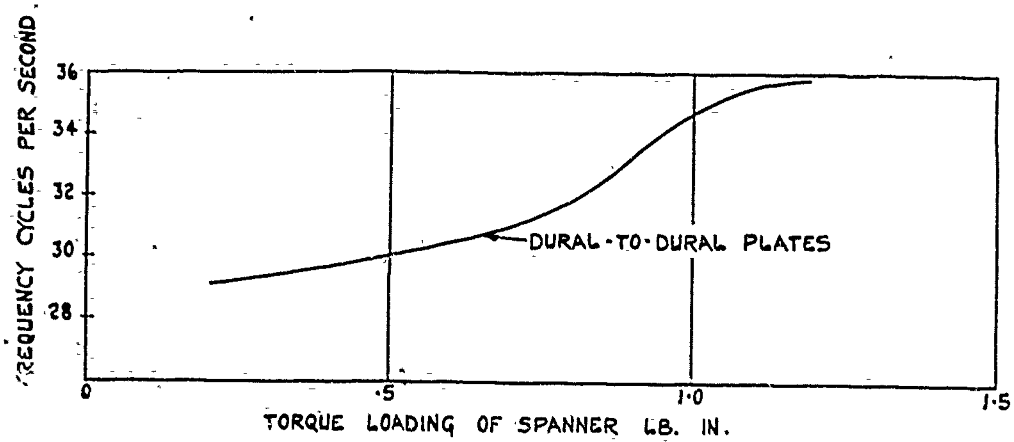


FIG. 9A. VARIATION OF NATURAL FREQUENCY OF LAMINATED BEAM II WITH TORQUE LOADING OF BOLTS.

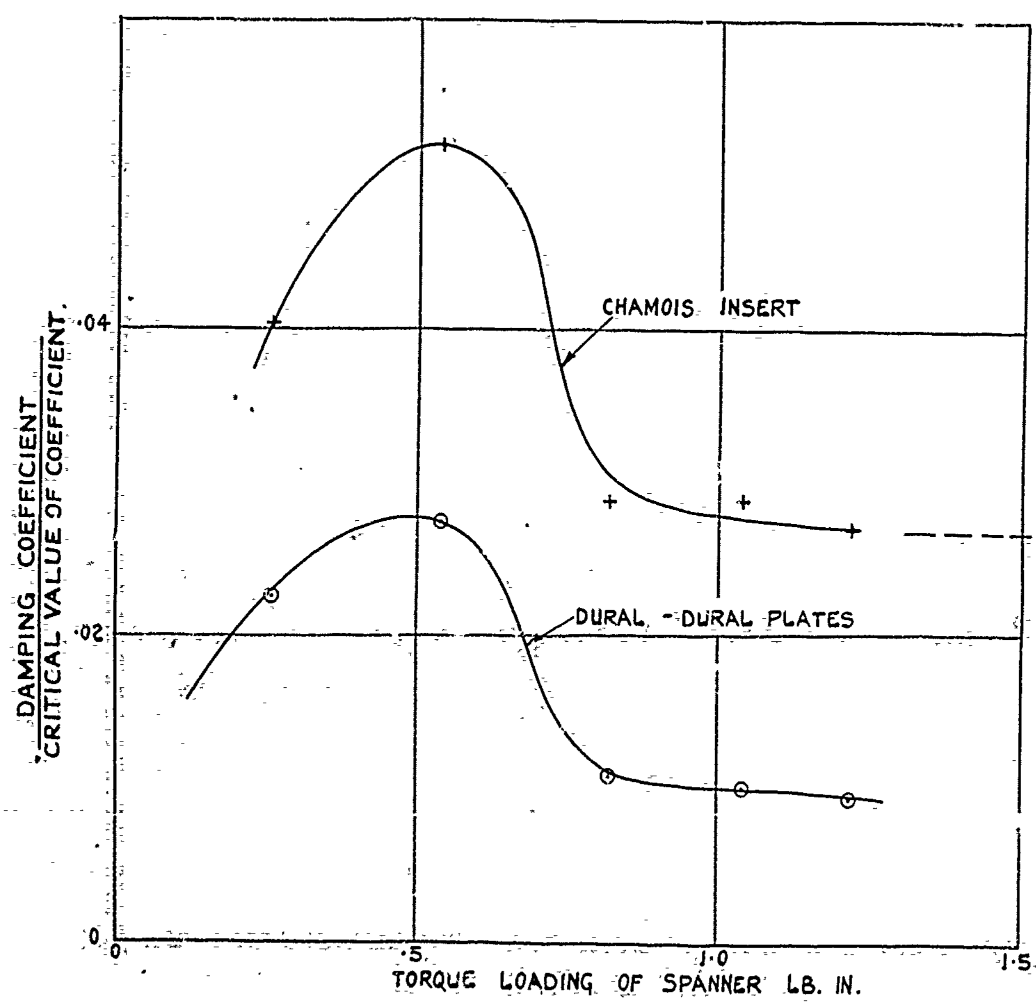


FIG. 9B. VARIATION OF DAMPING CAPACITY OF LAMINATED BEAM II WITH TORQUE LOADING OF BOLTS.

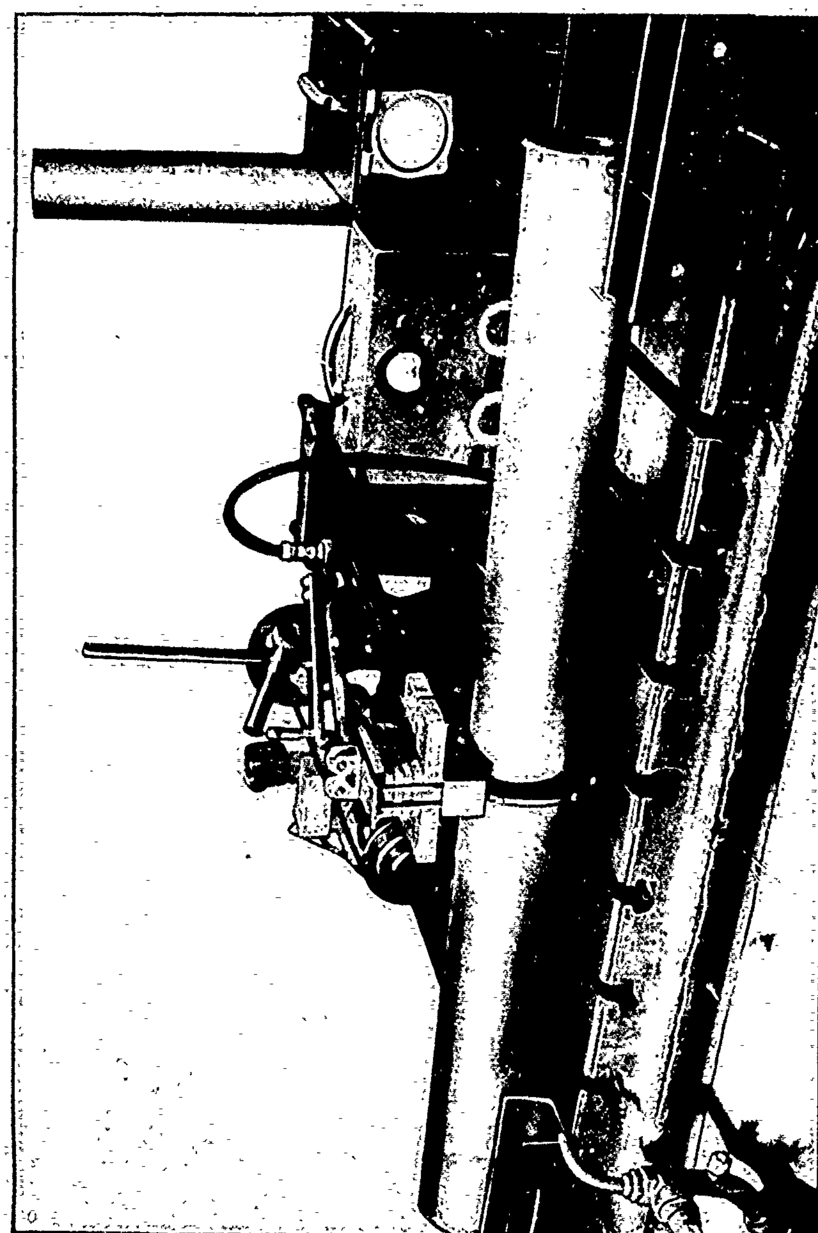


FIG. 10. TUBULAR TEST SPECIMEN.

R.A.E. NEG. NO. 146

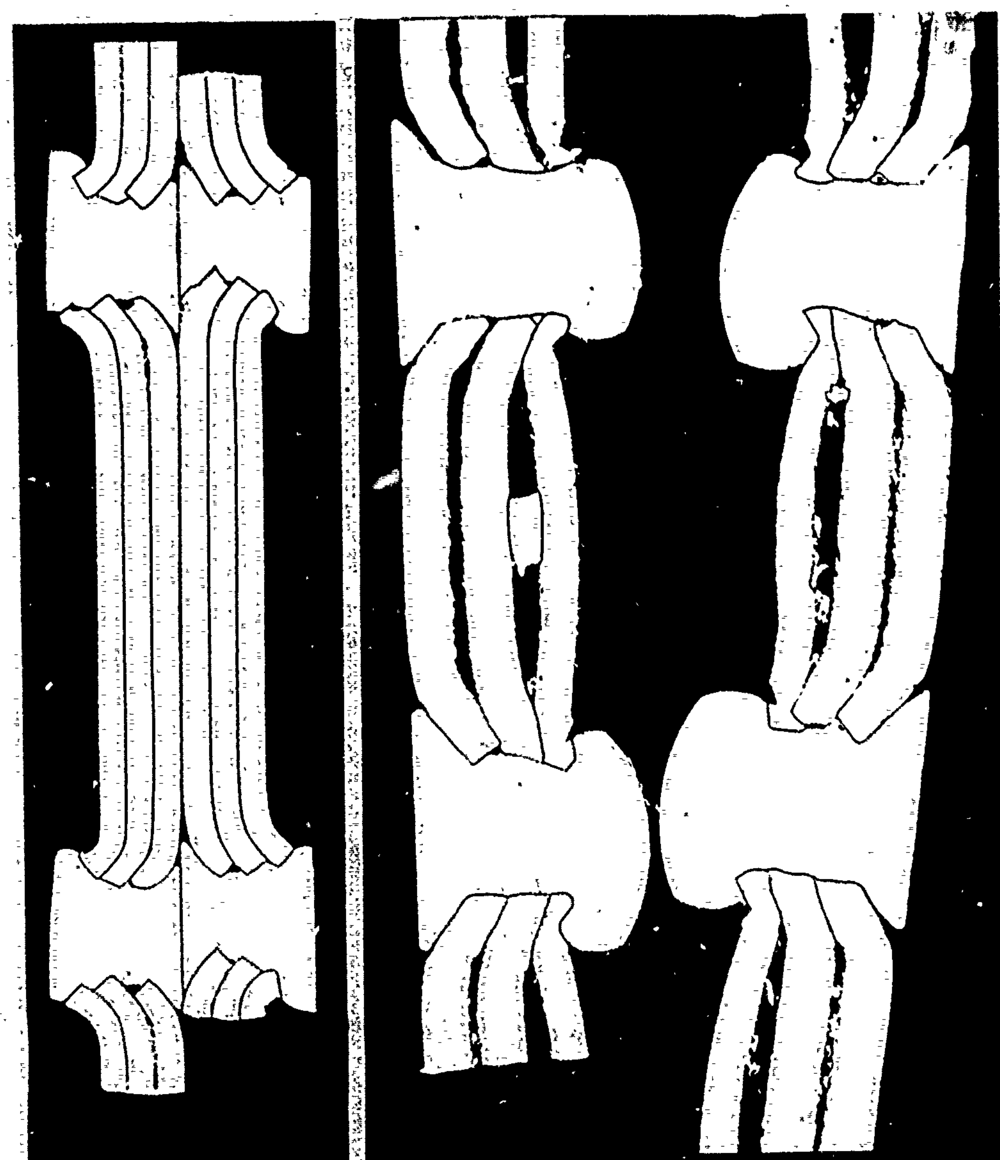


FIG. 11 & 12

CROSS SECTIONS OF RIVETTED JOINTS.

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ABSTRACT

An investigation was made to determine means of increasing damping in joints of a structure similar to a riveted structure by use of plastic inserts in joints. Apparatus used to compare damping of inserts made from different materials is described. Effect of thickness of inserts on damping was studied and variations of damping with temperature were obtained between -25° and +25°C for material poly-isobutelene. Investigation showed that an insert of poly-iso-butelene increased damping of riveted structures.

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